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Efficacy of Tactile Cues from a Limited Belt-Area System in Orienting Well-Rested and Fatigued Pilots in a Complex Flight Environment

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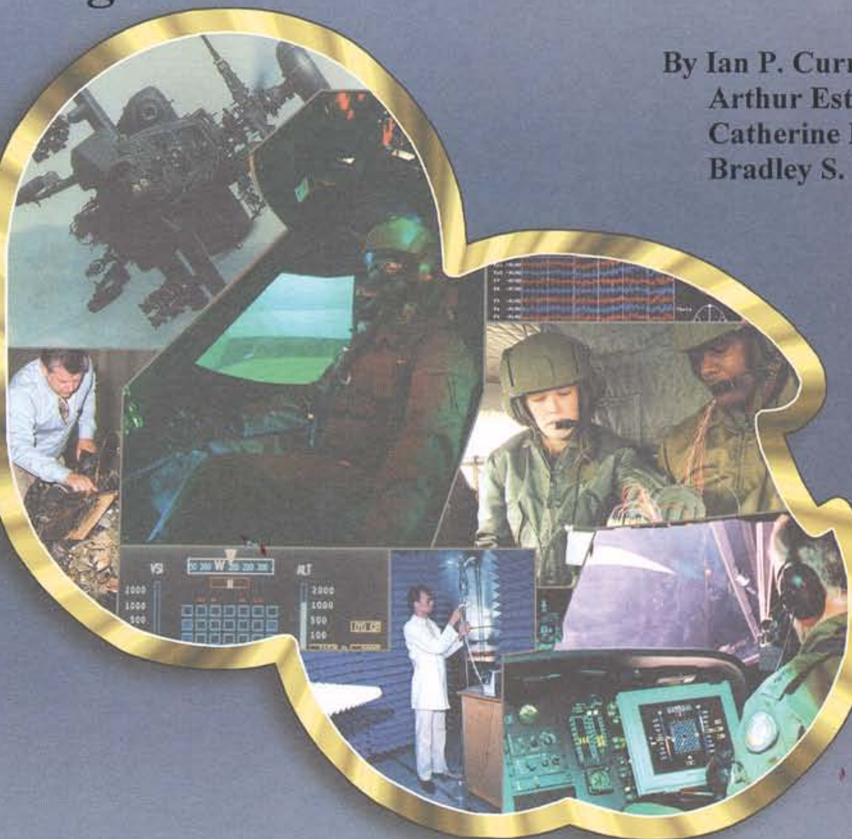

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14. ABSTRACT

In the years 2003-2005 the U. S. military lost in excess of $500M and 30 lives per year due to SD mishaps, over half of which involved brownout. Current standard Army aircraft cockpit displays do not provide drift information leaving the pilot guessing as to the direction and magnitude of the aircraft's drift vector when close to the ground. This information is critical to the safe landing of helicopters in brownout or whiteout conditions. This effort tested a system that provides drift information through the tactile sense (8 tactors placed every 45 degrees) via a belt around the waist. The belt was worn by pilots flying the USAARL UH-60 helicopter with vision restricted to the instrument panel only, the same pilots flew a repeated series of maneuvers close to the ground with and without the system before and after 37 hours of fatigue. The pilot's performance was significantly better using the belt than without in both rested and fatigued conditions. (Continued on next page.)

15. SUBJECT TERMS

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Report Documentation Page (SF298), Item 14. Abstract (continued):

The TSAS-Lite system used in this study demonstrated that a limited tactile display can provide increased mission effectiveness and safety in the critical areas of low speed maneuver near the ground in degraded visual conditions. The system also has the potential to increase a pilot's situational awareness and reduce both the perception of drift and the overall mental stress of flight in this challenging environment.

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Introduction and military significance

Many previous studies have shown that spatial disorientation (SD) plays a significant role in both the number and outcome of rotary wing class A-C accidents (Braithwaite, Groh, and Alvarez, 1997; Durnford, et al., 1995). More recent work has confirmed this and also highlighted the contribution of brownout conditions and aircrew fatigue in accident causation (Curry and McGhee, 2007). In the years 2003-2005 the U.S. military lost in excess of $500M and 30 lives per year due to SD mishaps.

Early work on tactile displays in the sixties by Bliss et al. concentrated on replacing the orientation information from lost vision in the blind with that provided by touch. This work showed that the tactile sense could provide at least as much orientation information as sight although the reaction to that information was slightly slower, being in the order of 200 ms as opposed to 75 ms (Van Erp and Van Den Dobbelsteen, 1998). This translated in a previous belt-area tactile display used in a tracking task (Schmid and Bekey, 1978) to a response time of 0.25 sec versus 0.10 seconds for a visual response. This slight delay is thought to be due to the conduction velocity of the nerves concerned and is of no practical significance in the application proposed in this study.

Normal balance and orientation on the ground are provided by correct visual, inner ear and skin/muscle/joint sensations. However, in aviation, the inner ear and skin/muscle/joint senses often provide false orientation cues. The only reliable source of information is that obtained visually. Using vision for orientation is intermittent, since vision must also be used for mission related information inside the cockpit. Understandably, the typical spatial disorientation accident occurs when the visual system is temporarily distracted or in reduced visibility.

Current standard Army aircraft cockpit displays do not provide drift information leaving the pilot guessing as to the direction and magnitude of the aircraft's drift vector when close to the ground. This information is critical to the safe landing of helicopters in brownout or whiteout conditions. Those few helicopters with instrumentation that do provide drift information do so via visual displays requiring the focus of an already visually-saturated pilot. This effort tested a system that provides drift information through the tactile sense (8 tactors placed every 45^{o}) via a belt around the waist.

To reduce the pilot's reliance on visual information during complex flight operations, the tactile situation awareness system (TSAS) has been developed to provide information via the under-utilized sense of touch (McGrath et al., 1998; 2004) which allows the pilot to maintain orientation while looking away from the aircraft instrument panel. The full TSAS array consists of an upper-body covering suit, shoulder straps and a seat all with lines of tactors which respond to hard and software in the aircraft that provide information on drift direction and magnitude. Unfortunately it is bulky, hot, expensive, difficult to maintain and therefore not a realistic option in the harsh field environments in which Army Aviation operates. The proof of concept flights were conducted in a UH60 helicopter and the results indicated improved aircraft control, increased situational awareness, and a reduction in pilot workload (Raj et al., 1998; McGrath et al., 2004). Although successful, the expense of fitting each pilot with a custom TSAS vest was

and remains prohibitive. The current study is unique in that it examines if tactile inputs in the limited area of a belt could prove as effective in providing helicopter drift information as the larger vest for much less expense. A successful demonstration would be significant as the drift information provided by the belt could be integrated into pilot take-off and landing training and procedures. The combination of cockpit instrument visual information with tactile drift information should provide the aircrew with a more complete "situational picture" when hovering, taking off or landing in areas of limited visibility, thus, potentially reducing or eliminating inadvertent drift and the accidents that ensue. When the US Army Combat Readiness Center's Composite Risk Management Strategy is applied to near zero visibility landings the outcome is unacceptable and thus gives impetus to finding a solution.

Study objectives

The novel and basic approach in this study is to assess whether a very limited system worn in the belt area is capable of being perceived and therefore, providing 'just enough' orientation information to fatigued pilots performing maneuvers near the ground in a degraded visual environment. If the system proves to be effective, then the tactile belt may be an inexpensive and reliable solution to the problem of flight accidents caused by degraded visual environments such as brownout and provide additional orientation cues to the fatigued pilot.

Methods

The study was a within-subjects, repeated measures design and was conducted by the U.S. Army Aeromedical Research Laboratory (USAARL) personnel using the laboratory's UH-60 helicopter. Eight volunteer pilots current on the UH-60 were trained in the UH-60 simulator in the use and interpretation of cues from a tactile belt (figure 1) which is driven by the TSAS system. This training consisted of a one hour simulator session on the first morning of the study (table 1). The TSAS system collects detailed orientation information from the UH-60 aircraft via the aircraft's ASN-128D-Doppler Global Navigation System and then sends signals to the belt tactors to provide orientation information to the pilot. Two volunteers were randomly assigned to participate during each session. The experimental procedure consisted of flights with a safety pilot (table 2), the first on the afternoon of study day one and the second 24 hours later on the afternoon of study day two after a completely sleep deprived night. Psychometric testing was undertaken throughout the experimental period as per the schedule in table 1, the individual tests are described below. The flights consisted of landing, take-off, and hover maneuvers while utilizing frosted goggles (figure 2) to limit the pilot's vision to his instruments. There were four test conditions: no belt and an eight-tactor, fully-functioning belt in both rested and fatigued states. The subjects were allocated which belt condition they began with, in a semi-random fashion to avoid an order effect while keeping the total numbers in each condition the same. The metric for the experiment was the accuracy of flying a set series of maneuvers in all conditions. Analyses of the data were through descriptive and inferential statistics after assigning numerical scores to flight accuracy.

Table 1.
Testing schedule.

	Day 1	Day 2
00:00		
01:00		
02:00		
03:00		
04:00		Cognitive testing
05:00		
06:00		Shower
07:00	In-Process,	Breakfast
08:00	Cognitive testing	
09:00	TSAS-Lite Simulator	Cognitive testing
10:00	Training	
11:00		
12:00	Lunch	Lunch
13:00	Test flight	Test Flight
14:00	Cognitive testing	Cognitive testing
15:00		Sleep
16:00		
17:00		
18:00	Cognitive testing	
19:00	Dinner	
20:00		
21:00		
22:00		
23:00	Cognitive testing	

Table 2.
Flight profile.

	Maneuver	Maneuver Standards	Data Collection Start/Stop
1	Stationary Hover	Maintain Heading, Altitude (10' AGL*), & Position	Start: Once hover is stabilized. Stop: 1 minute
2	Takeoff & Climb-out	Maintain ground track, continuous acceleration to 80 KIAS**, climb to 200' AGL for traffic pattern.	Start: At collective increase for takeoff. Stop: When climb past 200' AGL
3	Approach & Landing	Maintain ground track and continuous deceleration to terminate to the ground, full stop, at designated landing point.	Start: When descending through 200' AGL Stop: At landing to full stop with collective full down or recovery by safety pilot

*= Above Ground Level
**=Knots Indicated Air Speed

Description of the Tactile Situation Awareness System-Lite system

The prototype Tactile Situation Awareness System; TSAS-Lite (figure 1) tactile display system uses the sense of touch to provide spatial orientation and situational awareness information to aircraft operators. The TSAS-Lite system accepts data from the aircraft via the ASN-128D-Doppler Global Navigation System to obtain the aircraft position, velocity, and vector. This information is then displayed via the electromagnetic tactors located on the belt. During take-off, hover flight and approach to landing, location of the tactor on belt-line is used to indicate direction of helicopter motion, and tactor activation pulse pattern is used to indicate the velocity of the helicopter drift.

The system consists of a COTS PC-104 central processing unit (CPU) (Real Time Devices CMC6686GX233HR-128), a custom 8 channel tactor driver board and eight electromechanical tactors (Engineering Acoustics, Inc.). The tactors provide a vibrating stimulus at 90Hz +/- 20% with three rates of firing depending on pre-set ground speeds (0-15kts: 200ms, 15-30kts: 600ms, 30-45kts:1000ms), the sensation is similar in intensity to a standard electric toothbrush. The prototype belt is a flexible neoprene with Velcro fastenings and is worn sufficiently tight around the belt area to provide tactor contact while still being comfortable. The CPU and tactor drive

electronics are housed in a water resistant sealed housing, with data, tactor and operator switch interfaces. For operational use, the system could interface to existing military GPS units or COTS sensors. The system requires only timely digital data from position or direction sensors.

Figure 1. Tactile Situation Awareness System–Lite belt.

Figure 2. Frosted goggles.

Screening and informed consent

All volunteers were medically screened prior to taking part in the study and also were taken through a comprehensive informed consent procedure which they signed before any experimental procedures.

Inclusion and exclusion criteria

Eligible participants included both men and women (military and civilian) between the ages of 19-55 years. The upper limit age range of participants was restricted to 55 years based on research that shows that total sleep time and other sleep parameters change dramatically in

middle-aged individuals. To avoid introducing a substantial source of error variance into the study, the age of participation was limited to that range. Only healthy active duty, Reserve, National Guard, and DoD civilian UH-60 rated rotary wing pilots were used in this study. Any pilots with prior experience of TSAS were excluded from the study. Volunteers were taken on a "first come, first served" basis. Pregnant individuals would have been excluded from the study due to potential and unforeseen adverse effects on the fetus from the tactile belt but in the event only males volunteered for the study.

Data collection and testing

The testing schedule is shown in table 1. The cognitive testing referred to is a small battery of computer based procedures that have established normative data for comparison with our subjects:

Visual Analogue Scale (VAS)

The VAS consists of eight 100-mm lines centered over the adjectives 'alert/able to concentrate', 'anxious', 'energetic', 'feel confident', 'irritable', 'jittery/nervous', 'sleepy', and 'talkative' (Penetar et al., 1993). The extremes of each line correspond to ratings of 'not at all' and 'extremely.' Scores consist of the distance of the participant's mark from the left end of the line (in mm). The task was presented via computer.

Evaluation of Risks Questionnaire (EVAR)

Impairments in judgment are often apparent in situations where an individual engages in behavior where the risks far outweigh the probable advantages. The propensity to engage in or avoid risky behavior and situations was assessed by a brief 24-item paper and pencil questionnaire that has been used effectively to measure individual variability in risk assessment in previous research with Special Operations Forces (Sicard et al., 2001). Individuals mark a point along a 100mm bipolar visual analogue scale to indicate their preference for various types of risky activities. Administration time was approximately 5 minutes.

Profile of Mood States (POMS)

The POMS (McNair, Lorr, & Droppleman, 1992) is a 65-item adjective checklist that measures current mood states along six subscales: tension-anxiety, anger-hostility, depression-dejection, vigor-activity, fatigue-inertia, and confusion-bewilderment. Volunteers rated themselves from 1 (not at all) to 5 (extremely) for each mood-related adjective.

Psychomotor Vigilance Task (PVT)

Participants completed a 10-minute PVT. A pushbutton response to the visual stimulus (presented with an inter-stimulus duration of 1-10 seconds) was required. Data consisted of reaction times from stimulus onset to response and also the number of missed responses.

Flight data

The approach and take-off portions of the flights were measured on lateral deviation (drift) from a direct flight-path to or from a designated point and both were expressed as integrations of the acceleration in meters/sec. The hover portion was simply measured in meters from the datum. In addition altitude data was collected in all conditions, although this was in feet rather than meters.

Post-flight questionnaire

After each flight the subjects completed a questionnaire asking them to detail their impressions of a range of subjects from comfort to their level of situational awareness, full details and responses at Appendix A. The responses were on a Likert scale to allow analysis with a standard ANOVA.

Results

All statistical analyses were conducted using SPSS® 12.0 with significance set at an alpha level of .05 for all statistical tests. There were two main areas of analysis, that of the cognitive testing to establish a fatigue effect and that of the flight data to assess performance effects. Within the non-flight testing there was a further delineation between the subjective measures such as the POMS and the objective measures such as the PVT. All the cognitive tests were reported across sessions and displayed graphically.

Demographic data

Table 3 illustrates the diversity of the sample population who volunteered to participate in the study.

Table 3.
Demographics of participants.

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age	8	28.00	26.00	54.00	38.0000	9.27362
Flight Hours on UH 60	8	3026.00	54.00	3080.00	1219.8750	1260.52035
Flight Hours on Rotary wing	8	5855.00	145.00	6000.00	1984.8750	2038.88313
Morning/Evening Questionnaire Score**	8	28.00	38.00	66.00	53.7500	8.87613

** Morning Evening Questionnaire
Score of 16-41 = Evening Person
Score of 42-58 = Intermediate
Score of 59-86 = Morning Person

Visual Analog Scale

The VAS consists of eight scales: able to concentrate, anxious, energetic, feel confident, irritable, jittery, sleepy, and talkative. Across the sessions the energetic and sleepy scales achieved significance (p<0.01 in both cases) using a one-way repeated measures ANOVA. The results indicated a significant fatigue effect over time (figure 3).

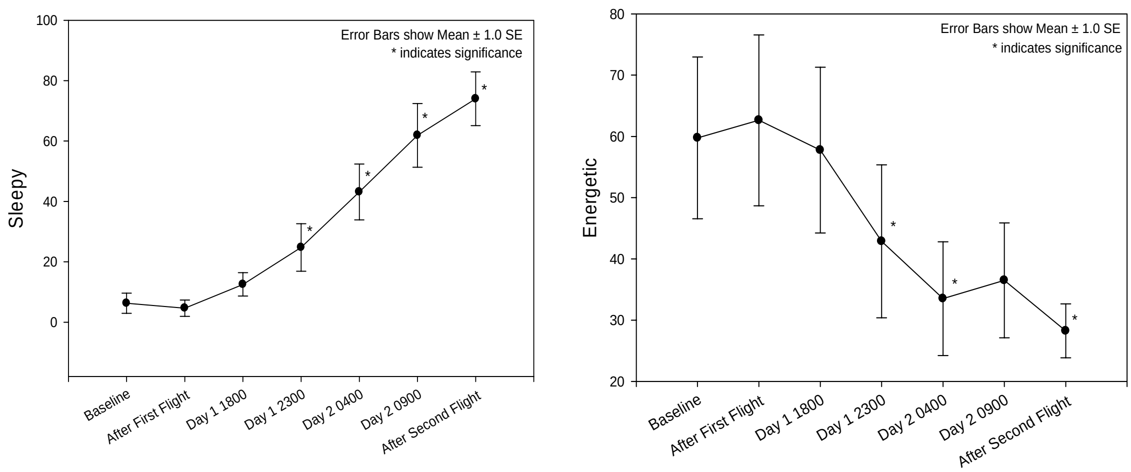

Figure 3. Visual Analog Scale sleepy and energetic measures.

Evaluation of Risks Questionnaire

The EVAR is a measure of three scales: risk taking, need for control and self confidence. The self confidence measure declined significantly (p=0.004) across the sessions (figure 4). The test of significance being a one-way repeated measures ANOVA.

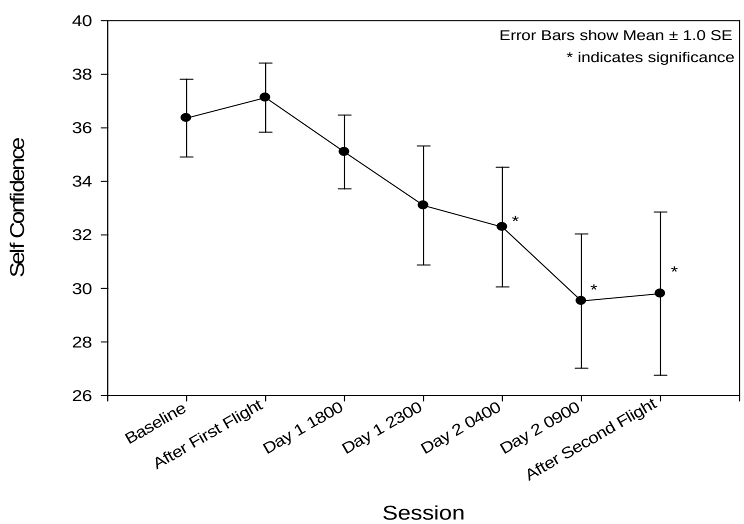

Figure 4. Evaluation of Risks Questionnaire self confidence measure.

Profile of Mood States

The POMS is a six scale measure of tension, depression, anger, vigor, fatigue and confusion. All these measures achieved significance ($p<0.05$ in all cases) across the sessions with the test of significance being a one-way repeated measures ANOVA indicating a decline in mood states (figure 5).

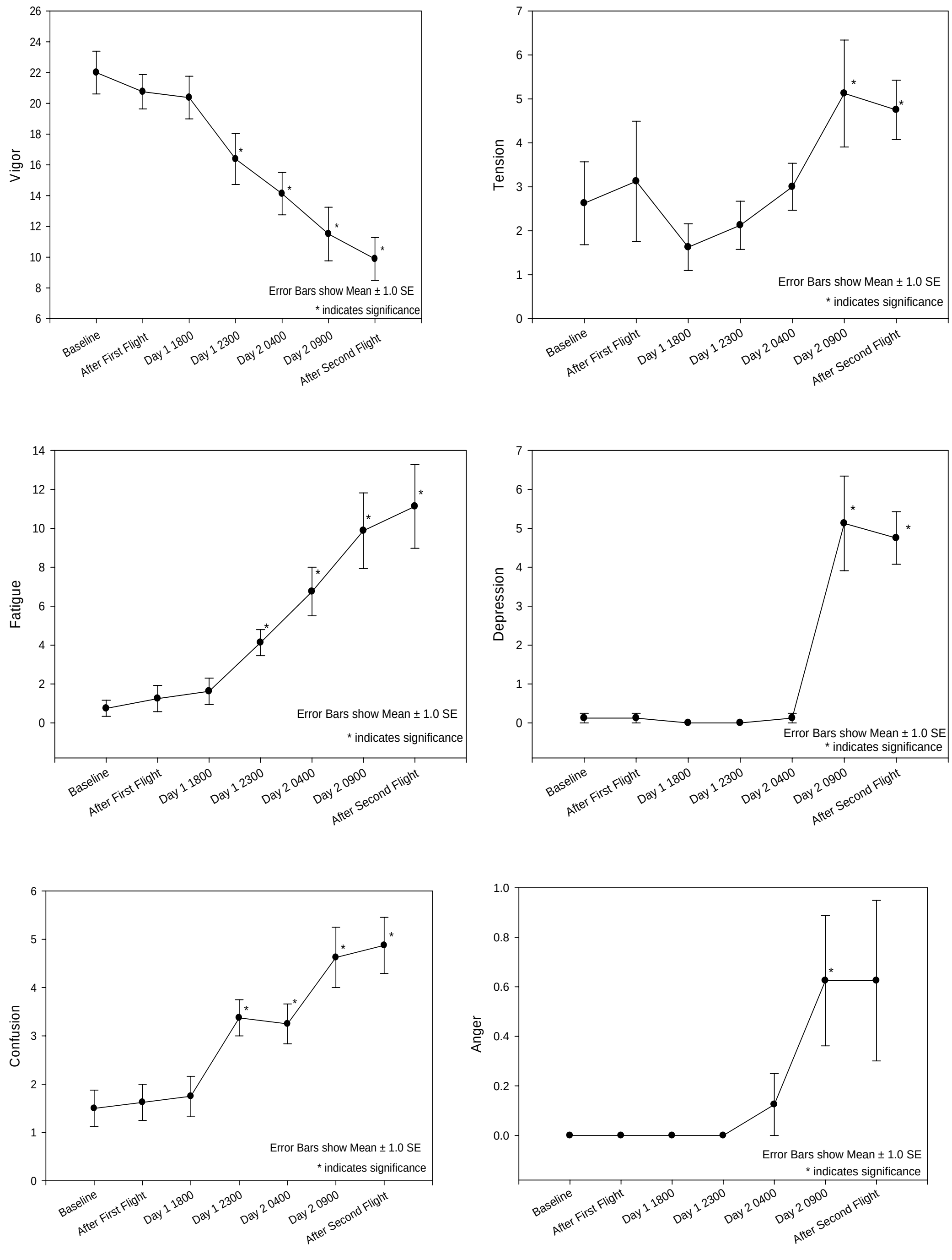

Figure 5. Profile of Mood States results.

Psychomotor Vigilance Task

The PVT is a simple automated measure of reaction time which also records lapses (responses over 500msec). The data were analyzed using a one-way repeated measures ANOVA across the sessions (7 levels). No significant differences were found across sessions for mean reaction time or lapses (figure 6).

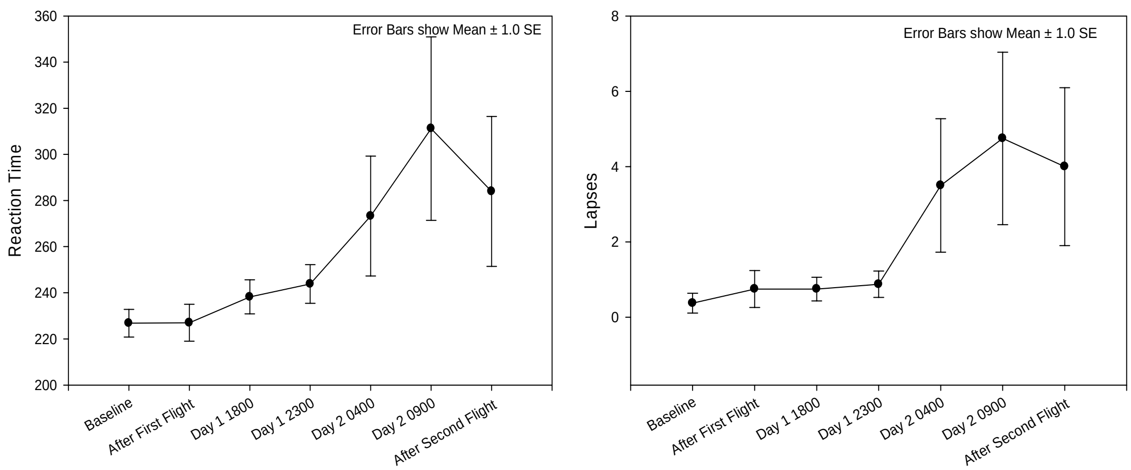

Figure 6. Psychomotor Vigilance Task data.

Flight data

The flight data were divided into three phases; take-off, approach to landing, and hover. All data were gathered from the Aircraft Information System (AIS). This system is unique to the USAARL UH-60 and gathers data in six degrees of freedom allowing full analysis of the flight performance. The take-off and approach data of particular interest was in drift (unwanted lateral movement from a horizontal azimuth). In the landing phase it is drift that produces many dynamic rollover type accidents and is the parameter not represented in the information provided by the flight instruments of the majority of aircraft (AH-64 and MH variants excepted). The drift information during take-off and landing has been displayed in rate form (meters per second). The hover data in lateral drift, heading and altitude represents an error from a set datum and the final output is a root mean square error derived from a score produced automatically by the AIS.

Analysis of the data showed that the tactile belt significantly improved drift control during takeoffs (p=.046) by well-rested aviators, yet demonstrated no significant differences in drift rates during approaches between any condition of belt activity or fatigue on a 2x2x2 repeated measures ANOVA (figure 7).

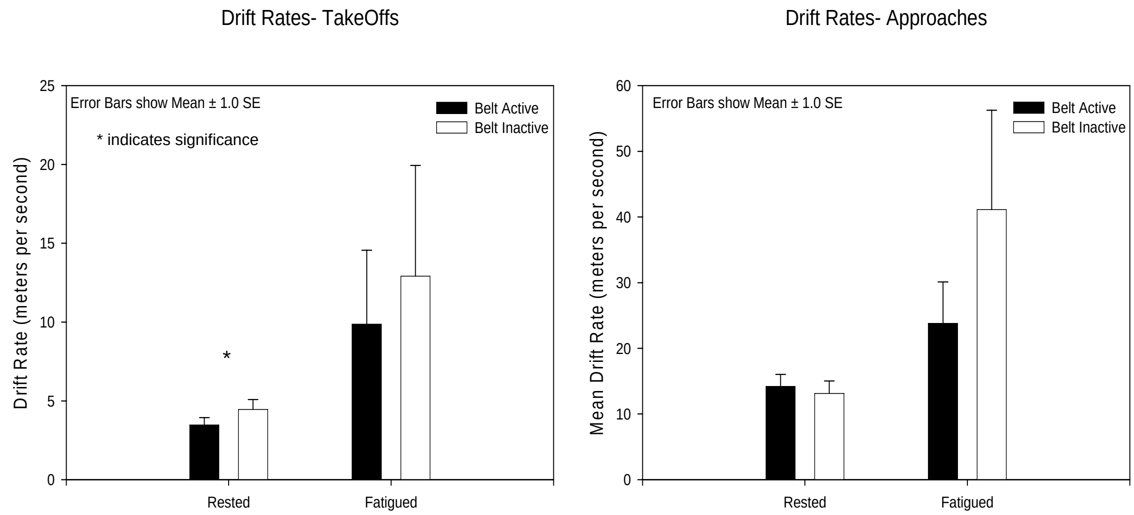

Figure 7. Drift during take-off and landing in rested and fatigued pilots.

The hover performance did show a significant improvement in drift control with the belt active as opposed to inactive (p=0.027 on 2x2 repeated measures ANOVA) (figure 8).

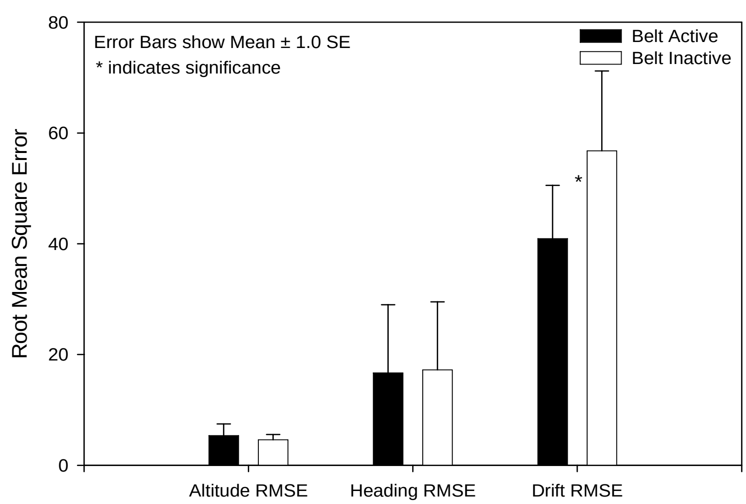

Figure 8. Hover performance.

Figure 9 shows an example of hover performance with and without the TSAS system. These ground track graphs illustrate the performance of the same participant under the fatigued condition and was typical of performance comparisons.

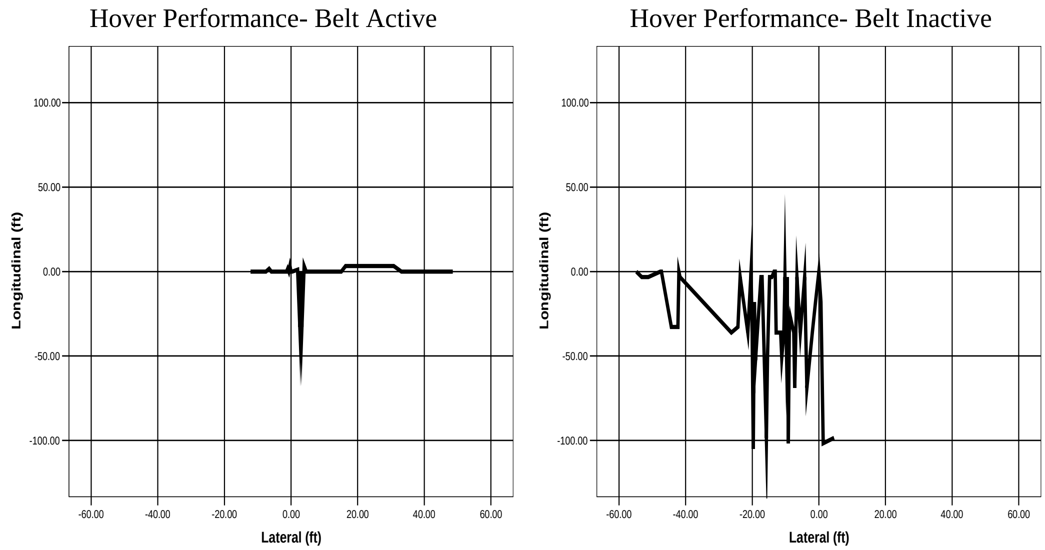

Figure 9. Ground track during hover performance.

Another measure used to examine flight performance was the number of times the safety pilot (SP) had to take the controls away from the test subject. These data are summarized in the tables below. There were 10 maneuvers (hover, takeoff, land, takeoff, land x 2) per person (8) = 80 with two days per person = 160 total maneuvers. Of the 160 total maneuvers, the SP had to take the controls only 22 times.

Table 4.
Total safety pilot takeovers.

	Average Altitude (feet)	Standard Deviation	Number of instances
Belt Active	8.00	4.663	9
Belt Inactive	8.75	3.744	13
Rested	7.8	3.823	10
Sleep Deprived	9.00	4.382	11

The most critical phase of flight is arguably the approach to land and indeed all the SP takeovers were in this phase, of the 64 approaches, the IP had to take the controls 22 times. When analyzed using the Chi Square test of Independence the difference in numbers of takeovers between belt active (9/32 = 28.1%) and belt inactive (13/32 = 40.6%) did not reach significance.

Post flight questionnaire

The post flight questionnaire (appendix) measured perception of drift, mental stress, cognitive demand, situation awareness, visual workload and physical workload. The subjects responded on a Likert scale and the data were analyzed using a 2x2 repeated measures ANOVA for belt condition and rested or fatigued. There was a main effect for fatigue for visual workload (p=0.032) and physical workload (p=0.041). In figure 10 the data for the belt condition main effects are summarized, all were significant (p<0.01) using the same statistical analysis.

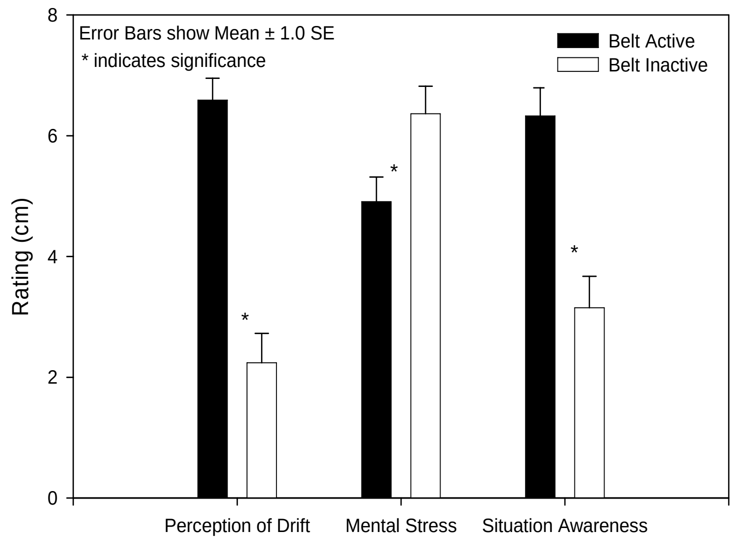

Figure 10. Post flight questionnaire results.

Discussion

The TSAS-Lite system used in this study has demonstrated that a limited tactile display can provide increased mission effectiveness and safety in the critical areas of low speed maneuver near the ground in degraded visual conditions. Results of this study have shown that that using TSAS-Lite pilots demonstrated enhanced control of hover maneuvers and the system also has the potential to increase a pilot's situational awareness and reduce both the perception of drift and the overall mental stress of flight in this challenging environment.

Demographics

The test subjects had a wide variety of experience in terms of both total flight time and UH-60 time. They also varied in age between the relatively junior and the more seasoned. They were all new to the TSAS system and this seemed to be the overriding factor with no discernible difference in performance due to either age or experience.

Fatigue

All of the subjective measures of fatigue used; the VAS, EVAR and POMS showed significant effects of that fatigue. Sleepiness and fatigue scores were raised over the course of the study and measures of energy and vigor were lower. The pilot's emotional state also changed significantly with the sleep deprivation with their anger, tension and depression scores going up and their self-confidence dropping. All of these measures were consistent across the period of the study with marked and significant trends.

The objective PVT data also showed consistent trends to a longer reaction time and more lapses with increased time awake although neither achieved statistical significance. Whilst taking this last finding into account the overwhelming impression is that these subjects were significantly fatigued by the thirty hours of wakefulness they underwent.

Flight data

In general, it is expected that poor performance will occur when situational awareness is incomplete or inaccurate (Endsley, 1995), and situational awareness by definition is compromised when external visual references are poor. Most previous attempts to ameliorate the effects of compromised visual conditions on flight performance have been exclusively based on giving the pilot a visual display with which to maintain his spatial awareness and orientation. These have ranged from the Ambient Attitude Indicator to the recently announced US Combined Services 'Sandblaster' initiative. The results in the flight portion of the study show that a simple tactile system can provide enough orientation information to the pilot to enable a safe landing with no external reference. In addition the tactile sense does not seem to be significantly impaired by fatigue or the stress of the situation. These results are significant for the hover (fatigued and rested) and for takeoff under rested conditions. In addition, the results demonstrate a strong positive trend for both the take-off phase under fatigued conditions and the approach phase of flight. The results of this study suggest that modern aircraft instrumentation provides virtually all the pieces of the orientation puzzle with the exception of drift information. When that drift information is added then low speed maneuver near the ground is potentially a lot safer.

By providing horizontal drift information the pilots were able to spend more time visually attending to other displays including the altimeter for altitude control. This ability to spend more time visually on other displays while gaining drift information from the tactile instrument resulted in reports of increased situational awareness and reduced workload and mental stress. These are clear advantages in the flight task and were consistent across fatigue with the pilot's perceptions of the system not changing during the course of the study.

Conclusions

Even in fatigued pilots, following 31 hours of sleep deprivation, the TSAS-Lite display helped augment traditional aircraft instruments in an intuitive, non-visual manner, particularly with the hovering task. Analysis of the study data showed that the tactile belt significantly improved drift

control during takeoff and reduced drift error during hover. In fatigued pilots, all measures of drift were better with the belt versus without the belt. In addition, fatigued pilots reported a significant reduction in visual and physical workload with the belt. Overall, the results indicated that the belt significantly improved pilot perception of drift and situation awareness, and reduced mental stress. This study's findings demonstrate the promise of tactile displays and support the continued development of future applications of tactile systems to better orient the aviator and possibly any vehicle operator to a world they cannot fully visualize.

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Appendix.
Comments from the post flight questionnaire.

<table>
<tr><td>Q- Did you feel the TSAS belt was effective in conveying drift information?</td></tr>
<tr><td>Responses-Rested</td></tr>
<tr><td>• Yes, accurate and immediate feedback
• Yes, it increased my confidence and situation awareness
• Yes, degree of effect unknown due to lack of experience with belt
• Yes
• Yes, but just a little bit slow in getting signals to the belt
• Yes, electrodes helped awareness
• Yes, direction feel. I could definitely feel drifting … and aft. Right front drift was more difficult
• Yes, gave a definite feel for drift</td></tr>
<tr><td>Responses-Fatigued</td></tr>
<tr><td>• Yes, began to fire immediately upon drift
• Yes, I was assured that the intended direction of flight was being maintained
• Yes, degree of drift not perceivable though
• Yes
• Very effective at a hover. Going through ETL and transverse flow it is very difficult to feel inputs from the belt
• Yes
• Yes, second time was more used to equipment and was able to correct quicker to drift info
• Yes, gave accurate info of drift</td></tr>
<tr><td>Q- Was the TSAS belt distracting in any way? Please Explain</td></tr>
<tr><td>Responses-Rested</td></tr>
<tr><td>• No
• No
• On ground, could belt be integrated into W.O.W. switch. Getting signal on ground teaches user to ignore it. Would not be a factor with more use
• Yes; experience with the TSAS belt is vital to its own success. For a new aviator, signal may become overwhelming
• No, going thru ETL on an approach it was difficult to differentiate between a/c vibs and belt vibs
• No
• No; only suggestion is to make a better belt so it fits tighter and allows for stronger pulse
• during high workloads, had to prioritize what info was important between instruments and TSAS</td></tr>
<tr><td>Responses-Fatigued</td></tr>
<tr><td>• No
• No
• Only on ground
• Yes
• No
• No
• No, tighter. Was able to get belt to stay on tightly and was able to feel all sensors
• At times almost info overload</td></tr>
</table>

Q- Was the TSAS belt helpful in any way? Please Explain
Responses-Rested
• Yes, helped with SA • Yes, by informing me of drift while I had no other cuing • Yes, helped with FWD movement. In another form 9,12,3 input might be sufficient 9ie IMC hover not a task) • Yes, it was relaying info before I could detect a drift. I was more certain of the movement of ACFT • Yes, even though there is a lag, the belt at least does make you aware of drift • Yes in drift control by highlighting movement • Yes, feel control touch. During hovering I was able to tell my drift right away than without it. Also helps with control touch • Gave a fairly accurate indication of aircraft drift
Responses-Fatigued
• Yes, definitely assisted with SA • Yes, situational awareness enhanced significantly • Reassuring on landing, helpful at a hover • Yes • Yes for drift • Yes/drift • Yes, hover, no app. During hover was able to feel all drift variations during flight or takeoff and approach. Could only feel forward sensor. Probably because of more distractions • Yes, helped very much with drift
Q-Was the TSAS belt comfortable (i.e., size, fit, location, etc.)? Please Explain
Responses-Rested
• Yes • Yes; Need to increase vibration strength of fwd buzzer (during ETC forward buzzer was somewhat difficult to sense) • Too loose, Velcro deteriorated • Comfortable yes, however it should fit snug in order for signals to be felt during shutter or approach • Yes • Yes • Yes and no, over flight suit, inside flight suit. Velcro, belt was not tight enough and with all the vibrations of the helicopter, it was tough to feel vibrations • Yes, just have to make sure tactors are unobstructed (ie zippers, seat belts, etc)
Responses-Fatigued
• Yes • Yes • Yes, no issues as in day 1 • Comfortable but I believe the belt will be a success providing it is made in such a way that it will properly and easily adjust to fit each pilot. Batt and company level training should require much more time than the subjects were given in order to be signed off for TSAS. One approach I made without the belt was 30-40 meters off runway. I never knew I was drifting. • Yes • Yes • Yes and no. could barely feel belt elastic, but sensors need to have higher intensity • Comfortable yes, may need better way to ensure sensor location and security

Q-Do you have any suggestions on how to improve TSAS belt? Please Explain
• Increase the vibration level. Because during the approach (in the shutter) the TSAS vibrations just about get drowned out from the A/C vibrations • More sensors on the belt perhaps; add a visual display in conjunction with the tactile cuing. Suggest day HUD, HMD or add-on basic lower display • Tie into WOW switch for disable on ground (see day 1 comment) • Ensure there is a way for it to fit everyone securely; somehow disable sensor with WOW switch to alleviate aggravation (if aviator finds it annoying they may not wear it) • Make belt buzzes more powerful • The vibrations of ETL overpower the feel of the belt. A stronger signal might help • Make belt adaptable to be worn closer to skin or up intensity of sensors and have integrated into Air Warrior vest • Possibly a much more foolproof method of positioning the sensors correctly. Also possible a study of how well it would correlate with the velocity vector cues with hud/avis set up
Do you think the TSAS belt has future applications? Please explain.
• Yes, in low visibility conditions (i.e., brownout or whiteout, ITO's) • Absolutely, this technology needs further testing and refinement for immediate integration into legacy cockpits of all airframes • Yes, if not in current state, possible (unintelligible) as discussed • Yes, future wars in dusty environments need protection against loss of life due to accidents. With proper training I believe the TSAS belt will save many lives • YES! Further research will develop much more accurate info to the pilots/crew • Yes • Yes, was very helpful in acquiring drift when completely brown or whited out. • Most definitely; anything illum or visibility is degraded for whatever reason

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